Building Detection in SAR Imagery

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ABSTRACT

Current techniques for building detection in Synthetic Aperture Radar (SAR) imagery can be computationally expensive and/or enforce stringent requirements for data acquisition. The desire is to present a technique that is effective and efficient at determining an approximate building location. This approximate location can be used to extract a portion of the SAR image to then perform a more robust detection. The proposed technique assumes that for the desired image, bright lines and shadows, SAR artifact effects, are approximately labeled. These labels are enhanced and utilized to locate buildings, only if the related bright lines and shadows can be grouped. In order to find which of the bright lines and shadows are related, all of the bright lines are connected to all of the shadows. This allows the problem to be solved from a connected graph viewpoint. Where the nodes are the bright lines and shadows and the arcs are the connections between bright lines and shadows. Constraints based on angle of depression and the relationship between connected bright lines and shadows are applied to remove unrelated arcs. Once the related bright lines and shadows are grouped, their locations are combined to provide an approximate building location. Experimental results are provided showing the outcome of the technique.

Keywords: SAR, Building Detection, SAR artifact effects, shadows, bright lines

1. INTRODUCTION

With the vast amount of Synthetic Aperture Radar (SAR) data available, processing all the data manually is difficult. Algorithms from the areas of image processing and computer vision can help process the large amount of data collected using air-borne systems. Approaches in the areas of terrain classification, *SAR artifact effects classification*, and automatic target recognition allow an analyst to concentrate on high level tasks. (SAR artifact effects refer to man-made objects that produce certain effects when interacting with the radar. Examples include bright lines and shadows. Bright lines are the result of the corner reflector created when the wall and ground meet. The shadow is the result of the scene behind the building being blocked by the building.) This paper proposes a technique for building detection in SAR that is efficient and effective in comparison to other proposed techniques. The technique makes a few assumptions. First, an automated algorithm has already labeled the bright and shadow regions of a SAR image. Second, daily SAR images are gathered which have the same frequency, flight path, polarization, and depression angle. This paper will provide a motivation for such a technique and discuss related work. Then an overview will be presented, followed by a more in depth discussion on the technique. Finally, some of the results will be presented to show the effectiveness of the technique.

1.1 Motivation and Overall Approach

There is a need to classify, characterize, and detect the different regions of SAR images. Detecting objects such as buildings is very useful but poses several problems. Buildings have many unique shapes, sizes, and heights. This creates a complication because there are no fix quantitative attributes that one can utilize to recognize a building. However, shadows and bright lines can be exploited to locate a building if they can be properly grouped. There are several techniques proposed by others which require multiple aspect images or a good interferometric SAR (InSAR) product. These techniques, however, can put demanding, stringent requirements on SAR data collection or are computationally expensive. A technique is required to locate a building that is efficient and not demanding on the gathering of SAR data and can handle images covering large areas (hundreds to thousands of square kilometers). Determining which bright lines and shadows are related without a priori information is a difficult task. Figure 1 is a block diagram of the proposed technique. The first block represents the required input data. Here, we use assume access to a SAR image product with the shadow and bright lines classified. Currently we use a technique based on superpixel

segmentation [9] and classification using the Kolmorogov Smirov test [11,12] and probabilistic fusion [10]. The second block finds subimages that contain possible buildings and to concentrate further processing. The third block enhances the shadows and edges by combing shadow fragments and determining the dihedral responses. In the fourth block, we represent the problem as a large connected graph with nodes representing the shadow and bright lines and the arc's representing relationships between the shadows and bright areas. Finally constraints are applied to reduce the number of connections and the building location is determined from the surviving subgraphs.
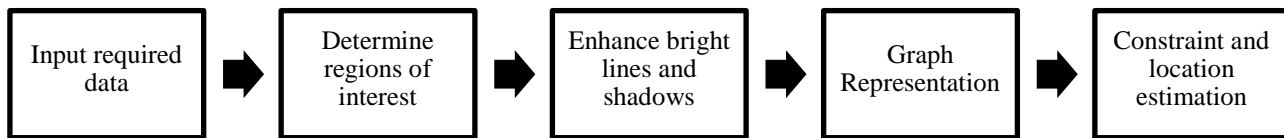
Input required data		Determine regions of interest		Enhance bright lines and shadows		Graph Representation		Constraint and location estimation

Figure 1. Block diagram for the proposed technique.

1.2   Literature Review

Several techniques have been proposed for building detection, which detect the buildings by finding the buildings edges. In [1] only bright lines were exploited to find buildings whereas in [2-4] shadows were added as another constraint. Bright lines result from the corner reflector created due to the interface between the building and ground [1]. To locate the buildings, SAR images with orthogonal flight paths were used to find multiple bright lines per building which produce parallelograms surrounding and outlining the buildings [1], [2]. To enhance the previous method, shadows were added to help with large building detection. The shadows help to provide another boundary that the bright lines do not provide [2]. While this technique worked very well, it requires careful flight planning to create orthogonal flight paths over the area of interest (which will not be available in all data sets). Building edges can also be detected using the watershed transform that is adjusted by bright lines and shadows [3]. The watershed algorithm find boundaries by filling regional minima until the two fills meet. At this point, the boundary is marked. Membership functions and rules were applied to objects, generated from detected bright lines and shadows, in order to create building hypotheses. The hypotheses were then used with the bright lines and shadows to find building edges [4].

Other techniques [5-7] did not utilize bright lines and shadows but instead used Markov random fields (MRF) to generate labels which model the a priori information of the scene. The labels represent the actual values of the data being utilized and can be generated for multiple types of data. In [5] the amplitude and InSAR phase were used, in [6] the real and imaginary parts of multiple co-registered SAR images were used, and in [7] the height, calculated from the InSAR phase, was used. This technique generates a parameter for the MRF distribution which describes the label and depends only on the surrounding values. The larger this parameter, the higher the probability is that the corresponding pixel is an edge.

These techniques are focused on locating the building through defining the buildings edges. For [1-2] the use of the Steger-operator to find the bright lines, orthorectification of the bright lines from the InSAR heights, and producing and testing the possible polygons becomes computationally expensive. The addition of shadows and building edges adds additional expense in [2]. The extensive extraction, downselection, and combination of bright lines and shadows followed by the classification of style of features in [4] is expensive yet robust. Then the generation of multiple hypotheses, selection of a hypothesis, and defining a buildings radar footprint adds more expense. On the other hand, for [5-7] finding the edges is computationally expensive because a large number of values must be generated to compute the expectations of the MRFs to solve for the parameter. This must be done across multiple iterations to insure that the parameter coverages. These techniques have no region of interest operator and waste computational resources on images that have no buildings or only a few buildings.

2. OVERVIEW

In order to detect buildings, bright lines and shadows are utilized. Bright lines are a result of the corner reflector created where the building and the ground intersect, while shadows are the result of the SAR geometry. SAR creates shadows when an object in the scene reflects the RF energy and prevents the energy from reaching objects behind the reflecting object. Objects other than buildings can also generate bright lines and shadows. However, due to assumptions about building sizes and knowledge about the systems configuration, bright lines and shadows not created by buildings can be

eliminated. Bright lines and shadows of interest can also be grouped together according to whether or not they are created by the same building.
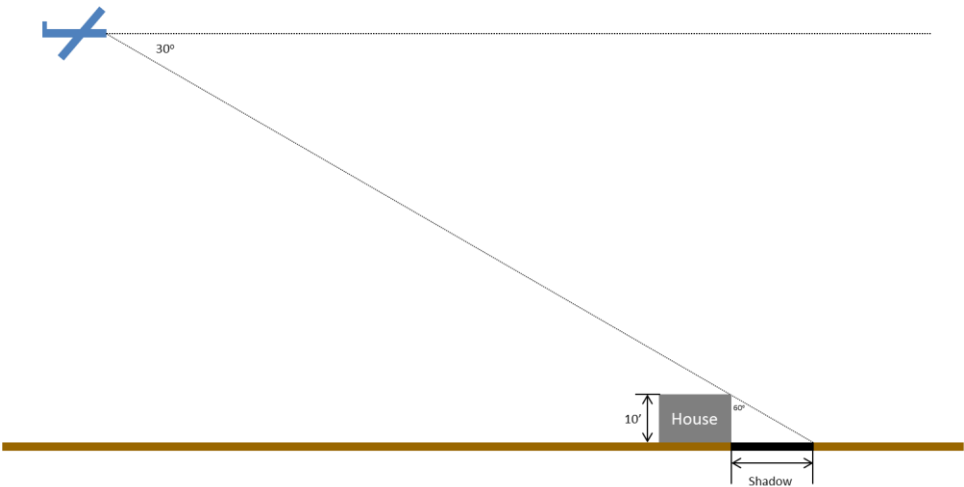

Figure 2. An example of how the angle of depression and a buildings height are used to determine the minimum length of a shadow.

A few constraints can be utilized to determine if the bright lines and shadows should be grouped. First, based on the angle of depression a minimum shadow length can be determined, see Figure 2. The taller an object, the longer shadow it will create. Buildings of interest can be assumed to have a minimum height. For the example above it is assumed that the minimum building height is ten feet and the angle of depression is thirty degrees. Therefore, the shadow must have a length of at least seventeen feet.
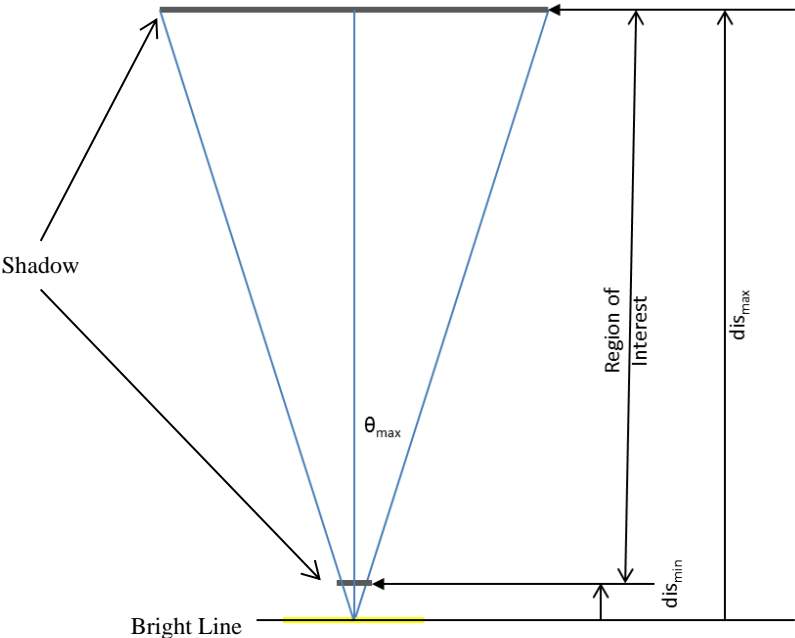

Figure 3. The acceptable range and angular region for the approximated center of a connected shadow under test.

Another constraint is that the bright lines and shadows must be in the same relationship. Bright lines will appear down range from shadows. Also the distance and angle between a bright line and a shadow must be in an appropriate range to

be part of the same building. The distance cannot be too great or it is not part of the same building, but it cannot be too close either. If it is too close then the object is not long enough to be a building. Similarly, the angle cannot be too great or the bright line and shadow will not be part of the same building. Figure 3 shows the acceptable region for the connected shadow's estimated center to be located, in order to be considered a valid connection.

Once the bright lines and the shadows are appropriately grouped they can be used to determine the location of a building. This is done by averaging the center of the bright lines and shadows. This provides a location for the building, however it is not guaranteed to be the center of the building, nor is it a bounding box for the building. However, this location should be contained within the area of the building.

3. TECHNIQUE

In order to utilize bright lines and shadows for locating the building, it is useful to first determine regions of interest where the bright lines and shadows could possibly correspond. To locate regions of interests an image of the scene is assumed to be available with bright line and shadow areas labeled. Figure 4 shows examples of the expected SAR products.
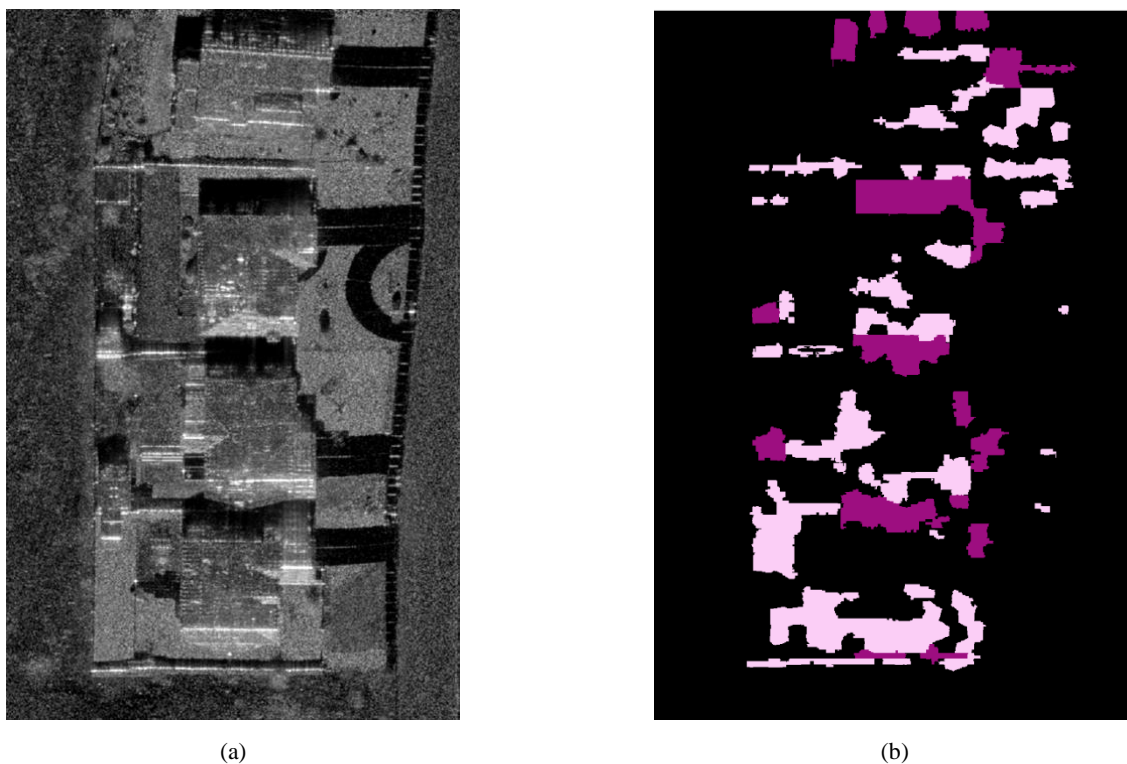

(a)   (b)

Figure 4. Examples of the expected SAR products. (a) Median back-scatter image. (b) Bright lines (pink) and shadows labeled (purple).

3.1   Region of Interest

The first step is to detect regions of interest (ROI). ROI's are subimages that could contain one or more building and allow the concentration of future processing to be confined to these areas. First, the combination of bright line and shadow labels are dilated. Then, the result of the dilation is grouped using four pixel connection and bounding boxes are found for these groups. Each of these bounding boxes is then checked to see if they contained both bright lines and shadow pixels. The idea with this dilation and grouping is that a building will have bright lines and shadows relatively close to each other. If these bright lines and shadows, related to a building, are aggressively dilated they will overlap and create one blob. Figure 5 shows an example of the aggressive dilation.

(a)   (b)

Figure 5. (a) Bright lines (pink) and shadows (purple) before dilation. (b) Bright lines and shadow areas after dilation. They have morphed into blobs which can be used to locate the regions of interest.

3.2   Shadow Enhancement

Once the regions of interest are located, the search for buildings is narrowed down to regions where the bright lines and shadows can be enhanced and located. To enhance the shadows, shadow labeled pixels are conditionally dilated. The condition for dilation is p-values. The classes are determined using probabilistic fusion [10]. The output of the fusion is a test statistic and a p-value. Here the p-value represents the probability of getting that test statistic or higher. The p-values are used to generate the labels and indicate how likely a given pixel corresponds to a specific label. Conditional dilation is performed by first dilating the shadow labels. The newly included pixels are then checked against the p-values. If the pixel is greater than a threshold of 0.01 for the p-values then it is kept as a valid labeled pixel. The idea is that pixels that are near to labeled pixels and have a large enough p-value, 0.01 or greater, are more likely to also be classified as that label. This step is important because it allows pixels that are truly part of a shadow but not labeled as shadow to be included in the shadow label. Figure 6 shows the difference between the pre-dilation shadow labels and the post-dilation shadow labels.
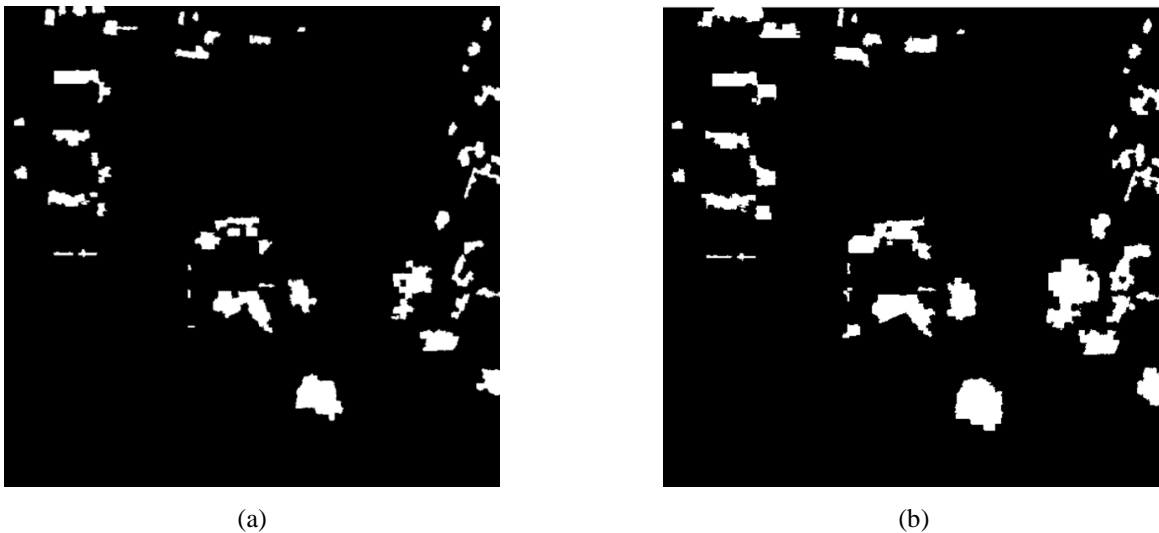

(a)   (b)

Figure 6. The result of implementing the conditional dilation. (a) Pre-Dilation (b) Post-Dilation

3.3   Bright Line Enhancement

In order to enhance the bright lines, the mean and variance statistics of the bright lines are estimated. This is required because the bright line labels contain more pixels than just the bright lines. The statistics are computed in the quarter power domain so the distribution will be approximately Gaussian. Then the assumption can be made that all pixels greater than the mean plus two standard deviations are bright lines. Once these are obtained, the lines can be further located and enhanced using the power ratio test presented in [8]. The ratio test looks at the ratio of the mean of the values in the target region, center white region, and the mean of the values in the clutter region, outside white ring. The bright lines found from the bright label statistics can be seen in Figure 7a, and the result of the power ratio test can be seen in Figure 7b. An example of the power ratio test regions can be seen in Figure 7c. If the ratio is above some threshold the pixel is set as a bright line pixel. To ensure that the bright line pixels are connected appropriately three sets of increasing line dilations and erosions are performed.

3.4   Graph Representation

The bright lines and shadows can be grouped to find a building because both bright lines and shadows are the result of the radar interacting with a building. Bright lines are the result of the corner reflector created when the wall and ground meet. This also locates the side of the building that is parallel to the flight and closest to the receiver. The shadow is the result of the scene behind the building being blocked by the building. Just as with the bright lines the shadows indicate the side of the building parallel to the flight path; however, it is the side furthest from the receiver. Although these effects may seem undesirable, for this purpose they are beneficial. (Bright lines and shadows are referred to above as SAR artifact effects.) A graph representation is used to group the bright lines and shadows into a building. Each shadow and bright line is assigned to a node in the graph. The arcs of the graph indicate the relationship between the nodes. The connection is based on the centroid of the bright lines and the shadows. The graph is fully connected in that all of the bright lines are connected to all of the shadows by their centroids. There is no need to connect all of the bright lines to other bright lines and all of the shadows to other shadows because these will be appropriately connected by finding the connections of bright lines and shadows.

(a)   (b)   (c)
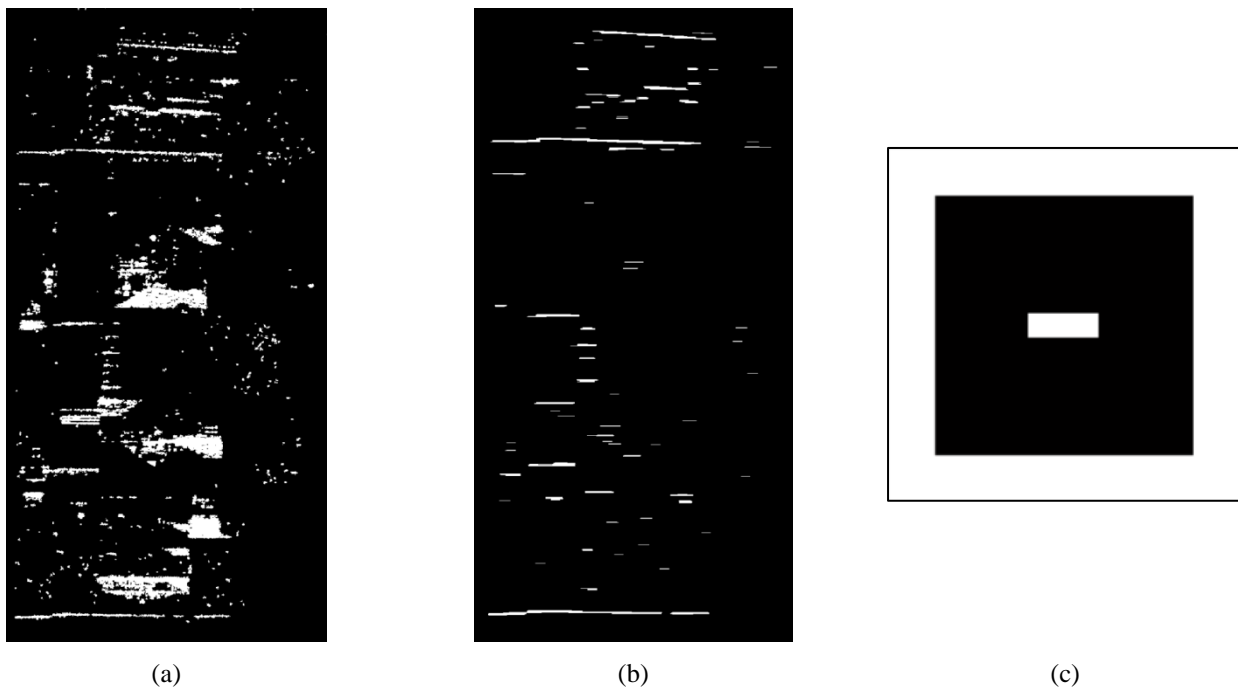
Figure 7. (a) The result of utilizing the bright statistic, in the quarter power domain, to find possible bright line pixels. (b) The result of enhancing the bright lines. (c) This is the regions used for calculating the ratio for determining if the pixel is part of a line or not. The outside white ring is the clutter region, the black region is the guard region, and the center white portion is the target region.

3.5   Graph Reduction using Constraints

Once all of the connections are made between bright lines and shadows there is no clear groups for buildings. The connections must be narrowed down in order to locate buildings. Some simple constraints are utilized to narrow down the connections. First, the length of the shadow is verified. If the shadow is too short then it cannot be the result of building. The minimum length of a shadow can be calculated by knowing the angle of depression and also the minimum allowable height of a building, see Figure 2. Any shadow that is shorter than the minimum is discarded as well as any connections to this shadow. As stated previously, bright lines connected to shadows are closer to the receiver. With this in mind, any connections that are connecting bright lines to shadows closer to the receiver are also discarded. Another constraint is the angle of the vector connecting the bright lines to shadows relative to the range direction. This further reduces connections between bright lines and shadows, since the angle must also not be too large, see Figure 3.

Once all of the bright lines and shadows in a group are known the building location can be approximated. To do this, first the shadow centroids are averaged and the bright line centroids are averaged. Then these two averages are averaged. What this ensures is that if there are a greater number of bright lines or shadows, the result will not be skewed one way or the other. With this result the building is now located. It is important to note that this is not a bounding box of the building or the exact center of the building. This also is very useful for narrowing down the location of the building so a more robust or computationally expensive technique can be utilized.

4. RESULTS

This section contains the result of applying the building detector on a region of interest from a scene with the required product types. Figure 8 contains the enhanced bright lines and shadows.
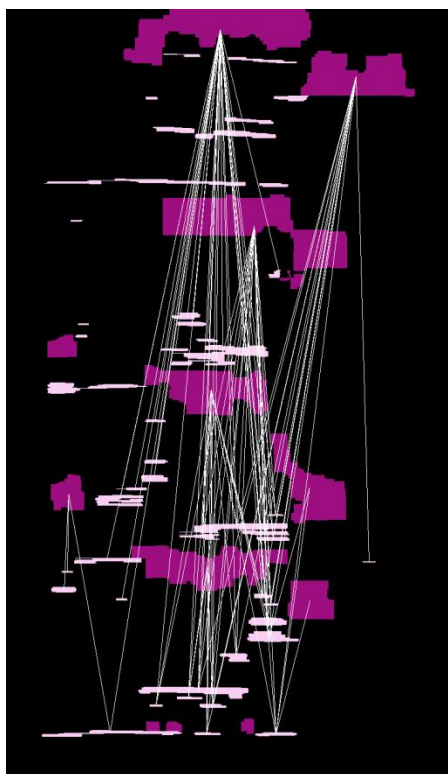

Figure 8. Region of interest extracted from an image containing enhanced bright lines and shadows. The purple patches are shadows and the pink patches are bright lines.
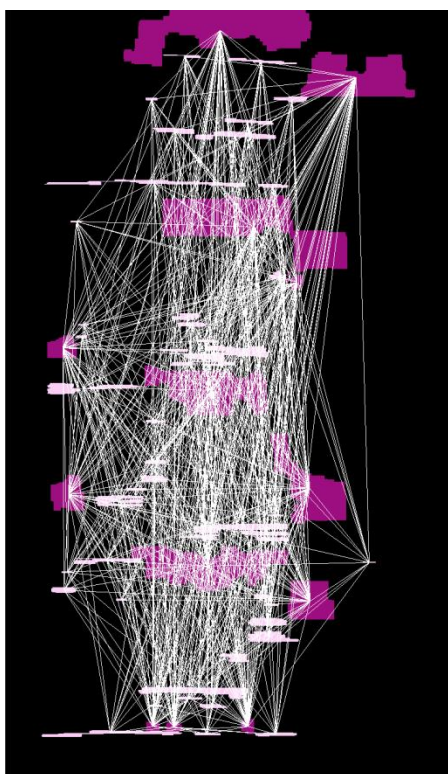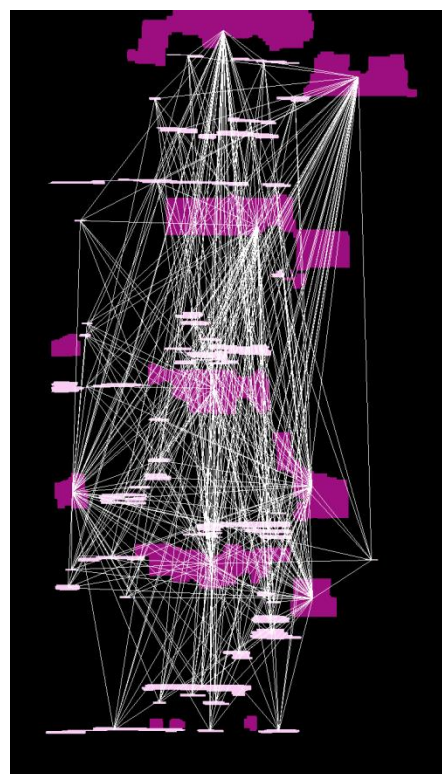
Figure 9. (a) All of the bright lines connected to all of the shadows. No connections removed. (b) Connections removed from failing the angle of depression requirement. (c) Connections removed from failing the angle requirements. (d) Connections removed from failing the distance requirements. There are two false detection in this region of interest. This is due to the limitations of the classifier and the conditional dilation. The driveways were considered as shadows which confused the detector.

Figure 9a shows all of the bright line centers connected to all of the shadow centers. This image makes it clear that there is a complicated combination of bright lines and shadows. With the current amount of connections it is extremely difficult to visually detect a building. Thus, it is important to reduce the number of connections. The angle of depression reduction test, see Figure 9b, does not reduce the connections by a large amount but it does remove connections that will increase the quality of the results. The constraint that reduces the most connections is the angle of the connecting vector. This constraint eliminates two connections issues. First, it ensures that bright lines are not connected to shadows that are closer to the receiver. Second, it removes connections that are at too broad of an angle for the bright lines and shadows to be related. Figure 9c shows the results of this constraint. The last constraint applied is the distance constraint. This checks that the shadows are not too close to the bright lines or that the shadows are not too far from the bright lines. If either of these occurs, then the shadow and bright line are not part of the same building. The result of this constraint can be seen in Figure 9d. Once the groups are determined the building location estimate can be obtained. This is done by first averaging the centers of the bright lines and averaging the centers of the shadows. Then the two averages are averaged. Figure 10 shows the results of determining the estimates. Out of 24 buildings in 4 images 17 buildings were detected and 7 buildings were missed. There was 5 false alarms and one building detected twice.
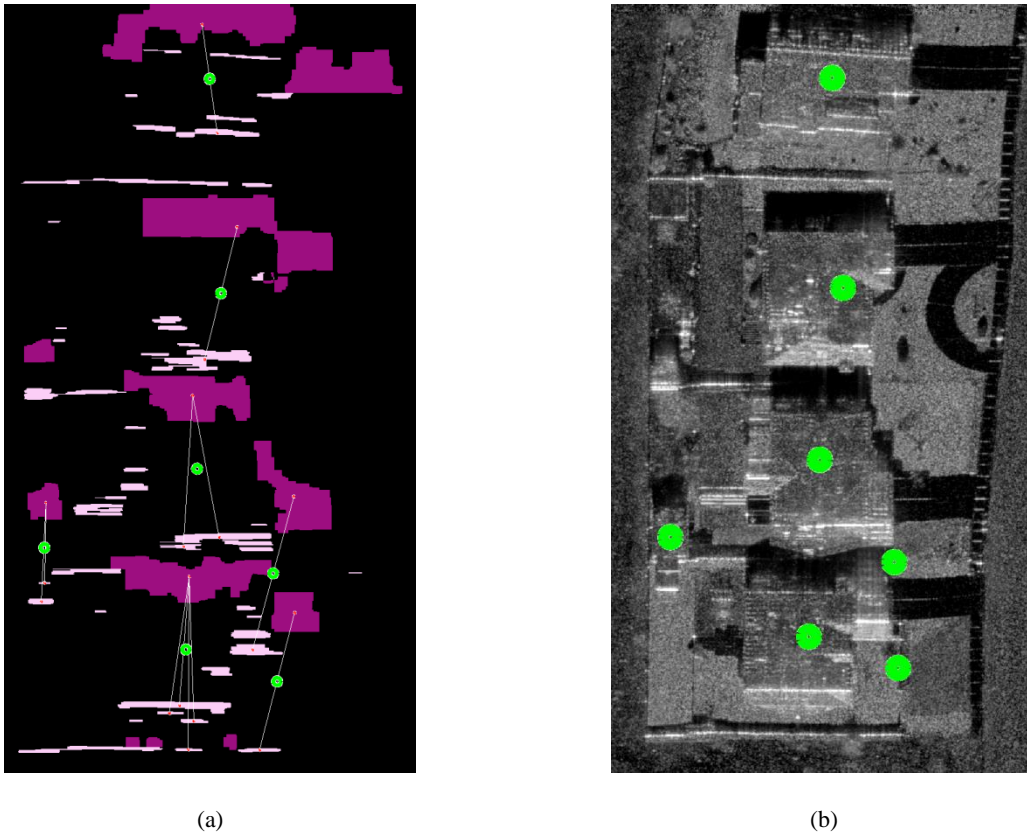

(a)   (b)

Figure 10. Building location estimates. (a) The estimates are obtained by averaging the bright lines centers and averaging the shadow centers. Then these averages are averaged. (b) Estimate shown on the SAR image.

5.   CONCLUSION AND FUTURE WORK

We have presented a technique that provides an efficient process to locate buildings in SAR images. It imposes minimal restriction or requirements for data collection. The only requirements are that the scene is observed multiple days and the images are co-registered. (The scene needs to be observed multiple days so the bright lines and shadow labels can be generated.) The technique may not provide a bounding box around the buildings like other techniques, but this technique is less computationally expensive and does not impose the strict requirements for data. By grouping the bright lines and shadows that appear in the image, buildings can be detected. From these groups, the location of the building

can be determined. The results show that the technique is quite valuable and has minimal issues. The false alarms are due to limitations in characterizing bright lines and shadows. The downsides for this technique are the requirements to accurately detect the bright lines and shadows. These are difficult processes because there are other objects in the scene that have a similar backscatter to that of the bright lines and shadows. Cement and water are examples of objects that are similar to shadow, while power lines and other narrow metal objects often appear similar to bright lines. The technique can be improved by improving characterization techniques such as the enhancement of bright lines and shadows, which are used for grouping the bright lines and shadows. The results are also very useful because they provide a starting point to more computationally intensive algorithms which can more accurately and robustly detect the buildings. This framework also could lead to a probabilistic graph framework what would give the probability of different shadow and bright line groupings.

ACKNOWLEDGEMENTS

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